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Original Article

Comparative effects of aerobic exercise, resistance exercise and yoga on metabolic profile and cellular ageing in type 2 diabetes mellitus

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ABSTRACT

Objectives: The prevalence of diabetes mellitus (DM) is rapidly increasing worldwide, with over 61.3 million people diagnosed with type 2 DM (T2DM) in India alone, estimated in 2019. Hyperglycaemia can be effectively managed by addressing lifestyle risk factors through physical activities such as aerobic training, resistance exercises (REs) and yoga. This study aims to compare the effects of these exercises on cellular ageing and metabolic profiles in individuals with T2DM.

Materials and Methods: The study included 120 patients, aged 25–40 years, diagnosed with T2DM, who were randomly assigned to four groups: Control, aerobic exercise (AE), REs and yoga (n = 30). Each group participated in 50-minute exercise sessions 3 times a week for 16 weeks. Gene expression of beta-galactosidase (β-Gal), marker for ageing, was assessed through complementary DNA prepared from peripheral blood ribonucleic acid, while metabolic markers – haemoglobin A1C (HbA1c), fasting blood glucose (FBG), post-prandial blood glucose, low-density lipoprotein (LDL), high-density lipoprotein (HDL) and cholesterol were measured at 3 time points: Baseline (week 0), 8 weeks and 16 weeks.

Results: The results demonstrated a significant positive effect on metabolic profile and cellular ageing, across all three exercise groups, which led to significant reductions in FBG at both 8 and 16 weeks: Yoga (P = 0.014, 0.017), resistance (P = 0.042, 0.029) and AE (P = 0.041, 0.011); no significant change in the controls. Post-prandial glucose and HbA1c levels also showed clinically meaningful reductions in the yoga (P = 0.013, 0.017), resistance (P = 0.020, 0.043) and aerobic (P = 0.022, 0.015) groups. Lipid profile improvements included significantly reduced LDL and increased HDL in all intervention groups. Furthermore, *β-Gal* gene expression, analysed through reverse transcription quantitative polymerase chain reaction, was significantly reduced in all exercise groups at both time points ($P \leq 0.01$ for all comparisons), indicating potential anti-ageing effects.

Conclusion: These findings underscore the common benefits of aerobic training, REs and yoga in controlling glucose levels and enhancing metabolic health in individuals with T2DM. All the exercise modalities used in our study were effective in reducing hyperglycaemia, improving overall metabolic function and reducing senescence.

Keywords: Aerobic exercises, Cellular ageing, Metabolic profile, Resistance exercises, Type 2 diabetes mellitus, Yoga

INTRODUCTION

Diabetes mellitus (DM) is a chronic disorder characterised by hyperglycaemia and disturbances in the metabolism of carbohydrates, fats and proteins due to defects in insulin secretion or action, or both. This condition leads to long-term damage, dysfunction and multi-organ failure, particularly to the kidneys, eyes, heart and blood vessels.[1] DM is linked with a high prevalence, severe complications, high costs and negative quality of life.[2] Type 2 DM (T2DM) involves a relative insulin deficiency and is characterised by decreased beta cell function, reduced insulin production and resistance.[3]

Exercise, together with medical nutrition therapy, forms the cornerstone of diabetes therapy and must entail at least 150 minutes of moderate-to-vigorous aerobic exercise (AE), over 3 days/week. Resistance exercise (RE), consisting of brief, repetitive exercises using weights and yoga, an ancient Indian practice involving mental and physical flexibility exercises, is also a well-established tool in the management of DM. RE improves muscle strength, increases muscle mass and enhances insulin sensitivity and glycaemic control[4-9] and yoga can also improve the biochemical indices of blood glucose and the lipid profile in patients with T2DM.

Cellular senescence, accelerated by hyperglycaemia through multiple pathways, is an important cellular mechanism to consider in the pathophysiology of T2DM.[10-14] Beta-Galactosidase (β-Gal) activity is the most extensively used biomarker for detecting cellular senescence.[15] Ageing leads to progressive functional decline in the immune system, making the elderly more susceptible to disease and infection.[16]

Our study explored the impact of the above exercise regimes – namely, aerobic training, resistance training and yoga – on metabolic profile and molecular parameters of ageing in T2DM patients.

MATERIALS AND METHODS

The research was carried out after obtaining approval from the Institutional Ethics Committee (IEC), with serial number: IEC/VMMC/SJH/PROJECT/2023-04/CC-336, date of approval: 24 May 2023, and written informed consent was acquired from all participants. The study recruited 120 T2DM patients from the endocrine outpatient department, who were randomly allocated to 4 groups – AE, RE, yoga and controls (who did not perform any structured exercise) (n = 30 each).

The study included patients diagnosed with T2DM, aged 25–40 years; body mass index-18–30 kg/m^2 and Haemoglobin A1c (HbA1c) <9.0%. Patients with uncontrolled DM, any history of cardiac, pulmonary, neurological disease or smoking were excluded from the study. Seven participants (3 [RE], 2 [AE] and 2 [Yoga]) exited the study due to voluntary withdrawal and non-compliance with the study protocol.

Intervention/treatment-exercise groups

Participants were allocated to one of the exercise training groups, using a simple randomisation method: Group A: Aerobic training group (n = 30); Group B: Resistance training group (n = 30); Group C: Yoga training group (n = 30) and Group D: Control group (no structured exercise, n = 30). Each training modality was conducted under supervision, for 50 min/session, 3 times/week, for a duration of 4 months (16 weeks). Participants in the exercise groups were asked to follow an isocaloric diet during the study period. A minimum attendance of 80% in all training sessions was required for a subject to be included in the study.

Details of training in intervention groups

Aerobic Exercise (AE)

Subjects performed exercise on a bicycle leg ergometer, training on, arm ergometer training and treadmill running, with gradual increases in intensity up to 60% of their maximum reserve heart rate. Each exercise was performed for 12–15 min, with a 5-min warm-up before starting and a 3-min cool-down afterwards, totalling 50 min/session.

Resistance Exercise (RE)

Participants performed exercises using weight machines and free weights to target upper and lower body muscles (Chest press, lat pulldown, shoulder press, leg extension, leg curl, leg press, biceps and triceps – for 10 times of three sets of exercise). Each exercise was performed for 3–7 min, with a 6-min warm-up before starting and a 1-min cool-down afterwards, totalling 50 min/session.

Yoga

Yoga sessions included a variety of physical, mental and spiritual practices (Yoga Asana – Surya Namaskar, Paschimottanasan, Vakrasan, Vajrasan, Uttana Mandukasan, Shavasan, Pavana Muktasan, Bhujangasan, Shalabhasan, Dhanurasan and Makarasa; Yoga Kriya – Kapalbhati and Yoga Pranayama – Anulom Viloma and Bharamri Rechaka), aiming to control the mind and alleviate physical and emotional suffering. Each exercise was performed for 1–10 min, with a 15-min warm-up before starting, and a 1-min cool-down afterwards, totalling 50 min/session.

Parameters and assessment

Metabolic profile

Blood samples were analysed for HbA1c, fasting plasma glucose, post-prandial blood glucose (PPBG) and lipid profile.

Cellular senescence

β-Galactosidase (β-Gal) expression was assessed from ribonucleic acid (RNA) isolated, using reverse transcription quantitative polymerase chain reaction (RT-qPCR) to evaluate cellular ageing in blood samples. Total RNA from blood samples of different experimental groups was isolated using TRIzol reagent and then subjected to reverse transcription using a complementary DNA synthesis kit (Thermo Fisher Scientific, MA, USA). RT-qPCR was performed in duplicates using SYBR Green quantitative polymerase chain reaction master mix (Thermo Fisher Scientific, MA, USA) on LightCycler 480 system-II (Roche Applied Science, UK) using gene-specific primers. The relative gene expression was calculated using Glyceraldehyde 3-phosphate dehydrogenase (GAPDH) as an internal control, and relative fold change was calculated by the comparative cycle threshold (using $2^{\text{delta-delta CT}}$) method.[17]

RESULTS

Fasting blood glucose (FBG) levels

Anthropometric data of all study subjects- the mean ± standard error of the mean (SEM) for age, weight, height, and body mass index (BMI) of participants across the four study groups: Yoga, RE, AE, and Control- were comparable in terms of age and BMI across groups, with mean ages ranging from approximately 34 to 38 years and BMI values between 22.0 and 23.4 kg/m². No significant differences were observed in baseline demographic or anthropometric characteristics among the groups [Table 1].

FBG: Substantial reduction in FBG levels was observed after all training programs. FBG significantly decreased at 8th and 16th week after yoga ($P = 0.014, 0.017$), RE ($P = 0.042, 0.030$) and AE ($P = 0.041, 0.011$), with patients doing yoga, showing the maximum reduction at 8th week and aerobic group at 16th week [Table 2 and Figure 1].

PPBG levels

PPBG levels also reduced significantly at 8th and 16th week – after yoga ($P = 0.040, 0.013$), RE ($P = 0.039, 0.021$) and AE ($P = 0.032, 0.028$). The patients doing AE improved at the 8th week, and those doing yoga demonstrated the maximum improvement at the 16th week [Table 2 and Figure 2].

Table 1: Anthropometric data of all study subjects.

Protocol	Age (Years)	Weight (Kg)	Height (cm)	BMI (kg/m²)	M	F
Yoga	34.100±0.709	61.233±1.975	165.600±1.398	22.081±0.521	22	8
Resistance	34.633±0.735	62.900±1.937	168.300±1.277	22.096±0.474	22	8
Aerobic	37.167±0.507	62.567±1.981	165.233±1.601	22.788±0.464	26	4
Control	37.700±0.476	62.400±2.173	162.500±1.787	23.427±0.466	16	14

M: Males, F: Females. Expressed as mean±standard error mean. BMI: Body mass index

Table 2: Comparison of levels of fasting blood glucose, post-prandial blood glucose and HbA1c, pre- and post-training.

Week	Groups			
	Control	Yoga	RE	AE
Fasting blood sugar (mg/dL)				
0 week	98.63±4.83	97.17±2.99	98.30±6.78	99.60±5.84
8 weeks	98.40±6.92	94.77±4.26*	94.66±6.82*	96.50±5.69*
16 weeks	98.86±7.31	91.80±5.08*	90.46±7.79*	92.63±5.83*
Post-prandial blood sugar (mg/dL)				
0 week	162.43±7.82	164.60±21.51	161.03±22.19	161.73±16.63
8 weeks	159.93±12.23	155.17±12.14*	150.70±15.06*	154.63±6.14*
16 weeks	161.87±10.56	148.33±8.31*	139.97±19.47*	150.97±6.43*
HbA1c				
0 week	8.58±0.45	8.61±0.34	8.64±0.41	8.68±0.29
8 weeks	8.60±0.52	8.40±0.31*	8.37±0.44*	8.44±0.45*
16 weeks	8.61±0.62	8.17±0.39*	8.12±0.51*	8.18±0.34*

In table, *t*-test used; $P<0.05$ taken as significant. *: $P<0.05$ compared to control, (Expressed as mean±standard deviation). AE: Aerobic exercise, RE: Resistance exercise, HbA1c: Haemoglobin A1c

HbA1c levels

HbA1c: Reduced at 8th and 16th week with yoga (P = 0.013, 0.017), RE (P = 0.020, 0.43) and AE (P = 0.022, 0.015). Maximum reduction at the 8th week was seen in the yoga group and in the AE group at 16th week [Table 2 and Figure 3].

Lipid profile (low-density lipoprotein [LDL] and high-density lipoprotein [HDL])

- LDL cholesterol: Significantly decreased at 8th and 16th week after yoga (P = 0.035, 0.041), resistance (P = 0.036, 0.040) and AE (P = 0.043, 0.026), with the most marked changes in AE group patients [Table 3 and Figure 4].

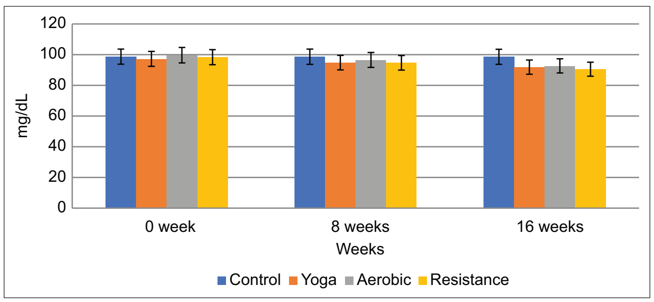

Figure 1: Comparison of level of fasting blood glucose, pre- and post-training.

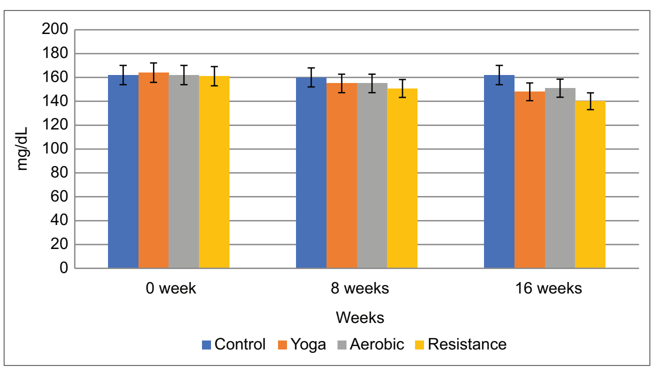

Figure 2: Comparison of level of post-prandial blood glucose, pre- and post-training.

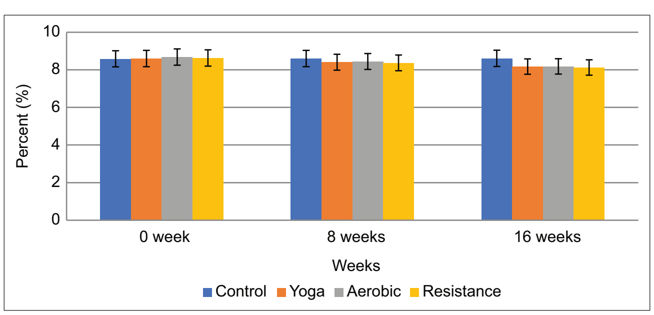

Figure 3: Comparison of level of Haemoglobin A1c (HbA1c) pre- and post-training.

- HDL cholesterol: Increased significantly at 8th and 16th week after yoga (P = 0.039, 0.022), resistance (P = 0.020, 0.041) and AE (P = 0.025, 0.011), with AE showing maximum improvement [Table 3 and Figure 5].

β-Galactosidase (β-Gal) expression

The specific results for β-Gal expression are analysed in fold change method[17] RT-qPCR analysis showed a significant reduction in its expression after yoga (P = 0.01, 0.01), resistance (P = 0.01, 0.01) and aerobic training (P = 0.01, 0.01), as compared to control at week 8th and 16th [Table 4 and Figure 6]. All groups were comparable in their effect on reduction.

DISCUSSION

The present study aimed to explore the effects of AE, RE and yoga on various metabolic markers, including fasting and PPBG, HbA1c, lipid profile and cellular ageing markers, in individuals with T2DM. We observed that all three interventions were effective in improving glycaemic control and ageing, though differences in the degree of improvement were observed. In contrast, the control group, which did not engage in any structured exercise, showed no metabolic improvements, highlighting the essential role of regular exercise in managing T2DM.

Regarding the reduction in blood glucose levels, AE demonstrated the most consistent and sustained 12.6% reduction in fasting and post-prandial glucose levels, as well as HbA1c, at the end of the intervention [Table 2]. Previous research has demonstrated that AE enhances insulin sensitivity and facilitates glucose uptake by muscles by inducing glucose transporter type 4 (GLUT4) translocation to the plasma membrane.[18,19] Yoga also showed a strong effect, closely followed by RE, with 10.4% and 13.1% reduction, respectively. Previous studies have established that RE improves muscle mass and insulin sensitivity[20] while yoga offers stress-relieving benefits that may reduce cortisol levels, apart from the benefit of physical asanas, contributing to better glucose regulation.[21,22]

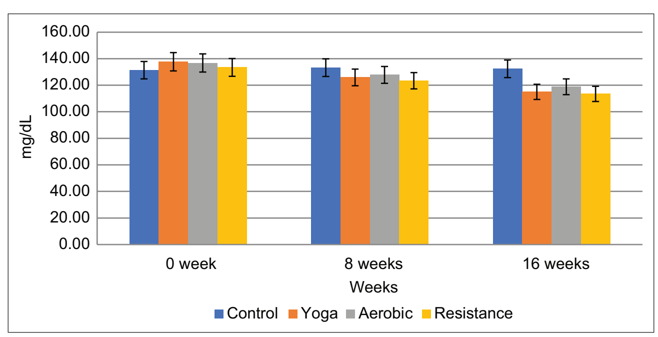

Figure 4: Comparison of level of low-density lipoprotein (LDL), pre- and post-training.

Table 3: Comparison of levels of lipid profile – LDL and HDL, pre- and post-training.

Week	Groups			
	Control	Yoga	RE	AE
LDL (mg/dL)				
0 week	131.37±18.41	137.70±20.81	133.43±16.60	136.73±16.49
8 weeks	133.20±18.77	125.83±21.93*	123.40±19.49*	127.77±17.18*
16 weeks	132.33±23.68	115.00±18.05*	113.47±17.18*	118.80±12.95*
HDL (mg/dL)				
0 week	47.10±7.35	49.07±8.58	47.40±8.34	48.77±8.54
8 weeks	47.50±7.61	53.50±7.67*	52.37±7.82*	53.63±7.76*
16 weeks	47.03±7.84	58.90±10.02*	56.33±6.87*	58.67±8.69*

In table, *t*-test used; $P<0.05$ taken as significant. *: $P<0.05$ compared to control, (Expressed as mean±Standard deviation). AE: Aerobic exercise, RE: Resistance exercise, LDL: Low-density lipoprotein, HDL: High-density lipoprotein

Table 4: Comparison of levels of beta-galactosidase expression, pre- and post-training.

Week	Groups			
	Control	Yoga	Resistance	Aerobic
Beta-galactosidase expression (fold change)				
0 week	1.010±0.010	0.971±0.080	1.031±0.147	0.980±0.134
8 weeks	1.015±0.045	0.700±0.071*	0.634±0.040*	0.645±0.045*
16 weeks	1.023±0.015	0.526±0.012*	0.525±0.023*	0.568±0.000*

In table, *t*-test used; $P<0.05$ taken as significant. *: $P<0.05$ compared to control, fold change in gene expression (Expressed as mean±standard deviation). AE: Aerobic exercise, RE: Resistance exercise

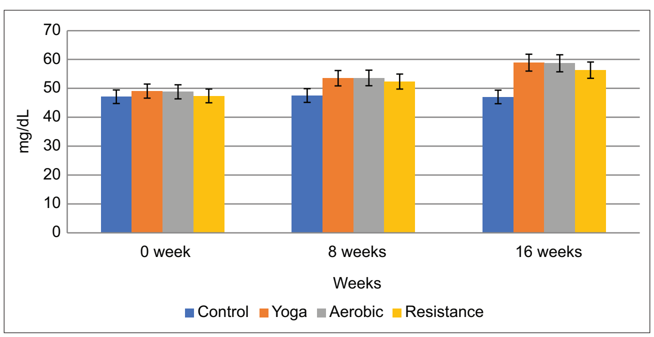

Figure 5: Comparison of level of high-density lipoprotein (HDL), pre- and post-training.

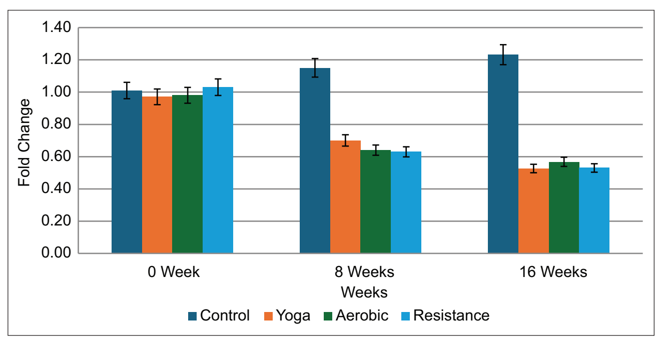

Figure 6: Comparison of levels of beta-galactosidase expression (fold change), pre- and post-training.

Further, the reduction in PPBG levels observed in all exercise groups supports the hypothesis that physical activity can modulate glucose spikes after meals. Studies by Kirwan *et al.* have shown that exercise improves post-prandial glucose levels by increasing insulin sensitivity and stimulating glucose uptake into muscle tissue; this effect is particularly beneficial in the post-prandial period when blood glucose levels are typically elevated.[23]

Regular physical activity can have a sustained effect on glycaemic control,[24] as evidenced by a significantly improved HbA1c, maximum in AE, followed by yoga and RE. This is an important finding, as even modest reductions in HbA1c have been shown to lower the risk of complications in T2DM by 21%, including nephropathy, neuropathy and retinopathy.[25] In addition to improved glycaemic control, exercise stimulates lipolysis in adipocytes through increases in sympathetic adrenergic activity, and this also contributes to better glucoregulation.[26]

Cholesterol metabolism was also significantly impacted by all modalities; AE showed the greatest reduction in LDL cholesterol levels, followed closely by yoga and resistance training. Similarly, an increase in HDL cholesterol was most prominent in the AE group, with yoga and resistance training also producing beneficial changes [Table 3].

Dyslipidaemia is a common comorbidity in T2DM, significantly contributing to elevated cardiovascular risk in these individuals.[27] Exercise increases the activity of the enzyme lipoprotein lipase and lecithin cholesterol acyltransferase, both of which decrease LDL, triglycerides and increase HDL. Among the effective adaptations, following aerobic activity is an increase in mitochondrial volume, followed by the activity of lipolysis enzymes, which increase the ability of fat catabolism during exercise.[28,29]

Specifically, reductions in LDL and triglycerides were observed in all three exercise groups, which is beneficial given the role of these lipids in atherosclerosis and cardiovascular disease development.[30] The increase in HDL levels is also noteworthy, as higher levels of HDL cholesterol are inversely related to cardiovascular disease risk.[31] In our study, the reductions in LDL and triglycerides and the increase in HDL across all three exercise modalities strongly suggest that regular physical activity reduces the risk of cardiovascular diseases, a major concern for people with T2DM.

Studies have shown that expression of β-Gal 1, an indicator of senescent cells, is significantly increased in pancreatic β-cells.[32] Our results showed that all the regimes, AE, RE and yoga ($P = 0.01$, 0.02 and 0.01, respectively) were equally efficacious in a significant reduction in β-Gal expression, indicating a shared potential in slowing cellular ageing processes.[33] This finding aligns with a growing body of research emphasising the anti-ageing effects of exercise, which is thought to reduce cellular senescence through mechanisms such as enhanced mitochondrial function, increased telomere length and reduced oxidative stress.[34] Other factors include activation of key signalling pathways, such as AMP-activated protein kinase and sirtuins, which regulate cellular metabolism.[35,36] The positive impact of exercise on cellular ageing also suggests its potential in delaying the onset of age-related diseases, including cardiovascular disease and neurodegenerative disorders, conditions that are particularly prevalent in individuals with T2DM.[36-39]

CONCLUSION

All three exercise types significantly improved metabolic markers, aerobic exercise showed the most consistent advantage, particularly in glycaemic and lipid parameters, whereas yoga offered strong benefits for long-term glucose control and cellular aging. All three led to improvements in metabolic profiles and cellular aging over 16 weeks, but AE consistently showed the most significant benefits, especially in glycaemic control and inflammation. This likely reflects AE's higher energy expenditure and cardiovascular demand, known to enhance insulin sensitivity, mitochondrial function, and reduce systemic inflammation more effectively than lower-intensity activity. Yoga, though less intense, still significantly improved metabolic and senescence markers, likely via stress reduction, autonomic regulation, and moderate movement—making it suitable for those unable to engage in high-intensity exercise. Overall, our findings support the benefit of regular physical activity in any form for T2DM management. However, AE emerged as the most effective and should be prioritized when feasible, with RE and yoga as supportive alternatives based on individual needs.

Although previous studies have reported the benefits of yoga in managing Type 2 Diabetes Mellitus (T2DM), our study contributes uniquely by directly comparing aerobic exercise (AE), resistance exercise (RE), and yoga in a single trial. Yoga led to significant improvements in metabolic profile and cellular aging markers, highlighting its value as a lower-impact alternative or complement to traditional exercises—especially for individuals unable to engage in strenuous activity. Since regular exercise adherence remains a challenge in T2DM, our findings emphasize that any consistent physical activity—whether AE, RE, or yoga—can offer substantial health benefits. This supports incorporating yoga into comprehensive lifestyle strategies for T2DM.

An important novel aspect of this study is the evaluation of cellular senescence through β-Galactosidase gene expression, a well-established marker of aging, which is rarely applied in exercise-based interventions for T2DM. This provides new insights into how different forms of physical activity may influence not only metabolic health but also cellular aging processes in diabetic individuals.

While our study assessed the independent effects of AE, RE, and yoga, future research could explore their combined or synergistic impact, as each modality may benefit T2DM through distinct physiological mechanisms.

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Ethical approval: The research/study was approved by the Institutional Review Board at Institutional Ethics Committee of the VMMC and Safdarjung Hospital, approval number IEC/VMMC/SJH/PROJECT/2023-04/CC-336, dated 24th May 2023.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patients have given their consent for their clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest: There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for

manuscript preparation: The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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